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FRACTAL ANALYSIS IN ASSESSING THE POROUS STRUCTURE OF FOAM GLASS

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It is shown that fractal analysis can be used to describe the structure of foam glass. It is proposed that the fractal dimension be used for quantitative assessment of foam-glass structure with fixed action of different technological factors. The interrelation of between the fractal dimension and the main technical characteristics of foam glass is determined.

Key words: foam glass, self-organization of structure, fractal analysis, fractal dimension, technological conditions, density, thermal conductivity.

Comparative analysis of the functional properties and technical characteristics of heat-insulation materials in the form of rigid tiles [1, 2] shows that the most promising material is foam glass, which possesses unique operating properties that meet the most stringent regulatory specifications.

Foam glass is obtained during thermal porization of batch, consisting of finely ground glass and a foaming agent, at temperatures 780 – 850°C. In the process the freely dispersed powdered system is transformed into the freely dispersed, highly organized structure of foam glass, comprising congealed glass foam with spherical or polyhedral pores 0.5 – 3 mm in size. These pores play the role of the structure carrier and form the disperse phase of the structure, while the interpore barriers consisting of glass, which possess the property of continuity, comprise the dispersion medium or phase. The quantitative ratio between these phases predetermines many technical characteristics of foam glass and depends mainly on the following technological factors: the chemical composition and dispersity of the glass, the form and dispersity of the foaming agent, and the temperature and duration of the foaming process.

At the usual temperatures glass batch can be classed as a stationary system. Only intense thermal action can transform this system into a dynamic developing one with continually changing characteristics, as a result of which self-organization of the final structure of the foam glass occurs. It should be noted that the viscosity η and surface tensions σ of the glass also affect the self-organization of the structure; their ratio σ/η characterizes the rate of formation of the new surface [3].

Diverse self-similar fractal structures (FS) with a definite fractal dimension (FD) form in the process of self-organization. The composition and properties of the initial foam-glass batch, the technological parameters of the process of thermal porization of the batch and the physical-chemical properties of the glass as it transitions into a pyroplastic state predetermine the fractal dimension.

It can be asserted on this basis that the FD must be used as a universal parameter to make a quantitative assessment of the porous foam-glass structure formed under the fixed action of different technological factors as well as to establish the relation between the FD and the main technological characteristics of foam glass.

The aim of the present work is to determine whether or not it is possible to use the FD to evaluate the effect of different technological factors on the thermal porization process for foam-glass batch and the relation between the FD and the properties of foam glass.

The FD of the surfaces of a porous space is determined experimentally by means of mercury porometry, the adsorption method and so on [4], which requires special equipment and therefore is quite laborious. Standard approaches, such as, for example, the method of vertical sections or the sectioning method [5], have now been developed for applying fractal analysis to the types of problems posed here.

The method of cubes was used in the present work [6]. This method is derived directly from the definition of FD by

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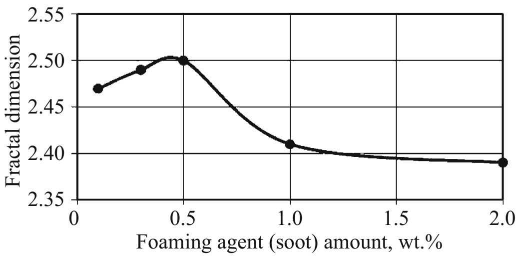

Fig. 1. Fractal dimension versus the foaming agent amount.

counting cubes. The algorithm is based on the following steps: a cubic lattice with lattice constant l is superposed on a surface stretched in the z direction. Initially, l is set at the $X/2$ level (where X is one-half the side of the surface), which yields a lattice of $2 \times 2 \times 2 = 8$ cubes. Then, $N(l)$ is the number of cubes which contain at least one pixel of an image. Next, the lattice constant l is halved successively at each step, and the process is repeated until l equals the distance between two neighboring pixels. The slope of the function $\log N(l)$ versus $\log 1/l$ gives the fractal dimensions D_f directly:

$$D_f = \log N(l)/\log(1/l).$$

Samples of foam glass obtained under laboratory conditions on the basis of ash-slag wastes from thermal power plants (composition 1) and foam glass obtained on the basis of different types of glass under laboratory and industrial conditions and differing by the composition of the foaming mixture and the technological conditions of foaming were the objects of experimental study (Table 1).

The experimental samples of foam glass based on ash-slag wastes from thermal power plants were obtained by means of a previously developed, two-step, energy- and resource-conserving technology [7].

For comparative assessment of the effect of the technological factors on the porization process for foam glass the foaming of the granulated material based on ash-slag wastes (13 mm in diameter granules) from thermal power plants was conducted at different process temperatures with different duration as well as with different percentage content of the foaming agent. After foaming 25 – 30 mm granules were sawed along the diameter and the FD was determined on the cross section of the structure.

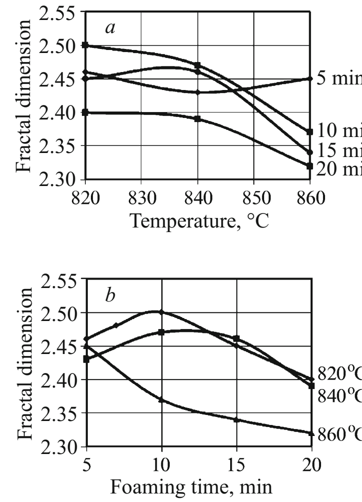

Fig. 2. Fractal dimension versus the foaming temperature (a) and time (b).

To determine the optimal amount of foaming agent, for which M-801 soot was chosen, the foaming was conducted at 820°C with 10-min soaking. The FD of the porous structure of the foam glass obtained was calculated by the method of cubes using Gwyddion software [8]. The dependence of the FD on the amount of foaming agent is presented in Fig. 1.

The maximum dimension FD = 2.5 is observed for 0.5 wt.% soot. This corresponds to the formation of the most uniform structure during the porization process. The structure is indeed fine-porous with a uniform distribution of the pores in the volume of the material. Thus, M-801 soot with content 0.5 wt.% is recommended for obtaining high-quality foam glass.

To evaluate the effect of other technological factors on the FD the foaming was conducted at temperatures 820, 840 and 860°C with 5-, 10-, 15- and 20-min soaking (Fig. 2).

TABLE 1. Composition of Experimental Batches and Glasses Based on Ash from Thermal Power Plants

No.	Glass type based on	Chemical composition of glass, %*						
		SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O
1	Ash-slag wastes	56.30	13.40	4.00	2.40	2.80	21.10	–
2	Ash	56.72	13.80	4.63	6.34	2.41	15.96	–
3	Loam	57.85	10.15	3.83	6.07	2.95	17.90	0.97
4	Lamp glass	64.78	11.85	0.11	4.88	3.10	14.28	1.00
5	Diatomite	59.30	10.54	3.56	4.16	3.65	16.27	2.52
6	Zeolite	58.82	10.53	3.62	6.14	1.78	17.13	2.50
7	Window glass	71.80	2.30	0.13	6.78	4.16	14.83	–

* Content, wt.%.

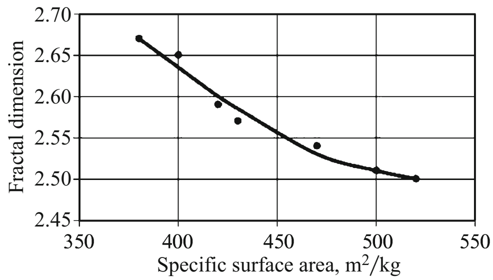

Fig. 3. FD versus the specific surface area of the foaming mixture.

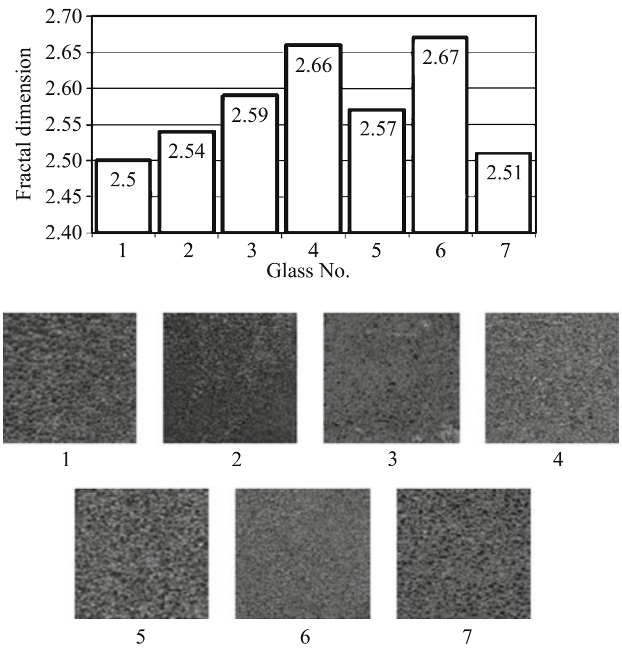

Fig. 4. Fractal dimensions and macrostructure of different foam glasses.

It was determined that for 5-min soaking there is not enough time for foaming to go to completion, and for this reason the plot is different, while for 10, 15 and 20 min it is similar. The FD reaches its maximum value at 820°C with 10-min soaking, which corresponds to the formation of an optimal structure. As temperature increases, the pore size increases and the structure becomes less uniform, which corresponds to a decrease of the FD.

As the foaming time increases, maxima corresponding to the formation of the optimal structure appear: at 820°C the soaking time is 10 min and FD = 2.5; at 840°C the soaking time is 10 min and FD = 2.47. At foaming temperature 860°C the structure obtained has large pores, and FD decreases as the foaming time increases at this temperature.

In summary, the optimal foaming regime can be determined and a quantitative relation between the fractal dimension with varying temperature and foaming time can be established from an estimate of the fractal dimension of the foam-glass structure.

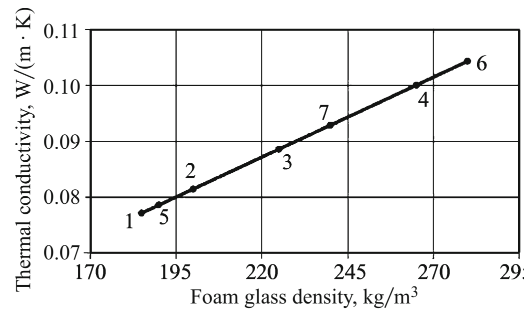

Fig. 5. Relation between the structure and thermal conductivity of foam glass.

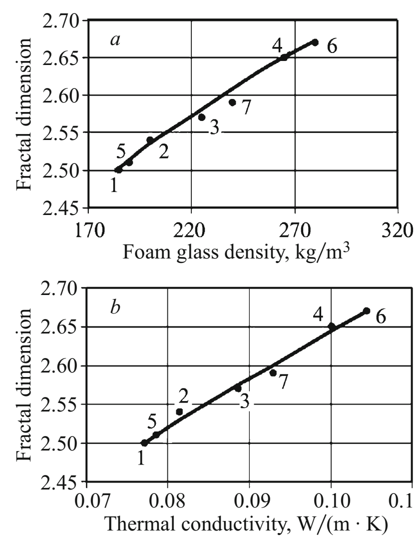

Fig. 6. FD versus the density (*a*) and thermal conductivity (*b*) of the foam glass.

An important technological factor in obtaining foam glass is the dispersity of the foam-glass mixture, which was determined from the specific surface area (PSKh-2). This dependence is displayed in Fig. 3, whence it follows that a uniformly porous structure of the foam glass with 1 – 2 mm pores is formed with porization of batch with specific surface area 500 – 550 m^2/kg and is characterized by FD equal to 2.5 – 2.52.

The foam-glass samples obtained from the glasses in Table 1 were studied to make a comparative analysis of the data obtained (Fig. 4).

These investigations established that the FD is a quantitative estimate of the process of thermal porization of foam-glass batches, which depends to a lesser degree on the composition of the initial batch (zeolite, diatomite, loam, ash-slag wastes, cullet) used in glassmaking and to greater degree on the chemical composition of the glass obtained. Foam glass with the optimal structure can be obtained in optimal thermal porization regimes, in which a correspondence is observed between the rate of change of the structural characteristics and the rate of the physical-chemical processes accompanying porization [9].

The second part of this work consisted of studies designed to establish a relation between FD and the technical characteristics of foam glass (Fig. 5, 6), obtained on the basis of the glasses in Table 1.

It was determined that FD increases with increasing density and thermal conductivity of the foam glass, and to obtain high-quality foam glass the fractal dimension of the porous structure must be 2.5 – 2.6.

In summary, the present investigations have shown that the structural quality of the foam glass formed can be evaluated quantitatively by means of the fractal dimension, which is predetermined by technological factors, such as the specific surface area of the batch and the composition of the glass. The fractal dimension of the structure of a porous body is a sensitive characteristic reflecting the mechanism of the formation of the porous structure in the process of obtaining the foam glass; it can also be used to estimate the technical characteristics of the foam glass obtained.

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